Adjustments to Improve the Estimation of Usual Dietary Intake Distributions in the Population[1]

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ABSTRACT We reexamined the current practice in estimating the distribution of usual dietary nutrient intakes from population surveys when using self-report dietary instruments, particularly the 24-h recall (24HR), in light of the new data from the Observing Protein and Energy Nutrition Study. In this study, reference biomarkers for energy (doubly labeled water) and protein [urinary nitrogen (UN)], together with multiple FFQs and 24HRs, were administered to 484 healthy volunteers. By using the reference biomarkers to estimate the distributions for energy and protein, the data confirmed previous reports that FFQs generally do not give an accurate impression of the distribution of usual dietary intake. The traditional method applied to 24HRs performed poorly because of underestimating the mean and overestimating the SD of the usual energy and protein intake distributions, and, although the National Research Council and the Iowa State University methods generally give better estimates of the shape of the distribution, they did not improve the estimates of the mean (10–15% underestimation for energy and 6–7% underestimation for protein). Results for urinary potassium, a putative biomarker for potassium intake, and reported potassium intake did not display this underestimation and may reflect either differential underreporting of foods or inadequacy of the potassium biomarker. A large controlled feeding study is required to validate conclusively the potassium biomarker. For energy intake, adjusting its 24HR-based distribution by using the UN biomarker appeared to capture the usual intake distribution quite accurately. Incorporating UN assessments into nutritional surveys, therefore, deserves serious consideration. J. Nutr. 134: 1836–1843, 2004.

KEY WORDS: • *biological markers* • *energy intake* • *nutrition assessment* • *questionnaires* • *reference values* • *underreporting* • *surveillance*

A major purpose of dietary surveillance or monitoring is to evaluate dietary intake relative to some standard. Standards may be averages, around which the population's intake should be distributed, or thresholds, above or below which the population's intake should fall, but they are all established with regard to *usual* intake, generally defined as the long-run average daily intake. This is important because diets vary considerably from day to day. Nonetheless, the primary assessment method used in dietary surveillance is the 24-h dietary recall (24HR)[3] (1), an instrument that inherently captures intake only a day at a time and thus yields an excessive amount of within-person variation. What is needed instead is an estimate of the distribution of usual food intake.

FFQs (2–6) are designed to capture usual intake, but there is no general agreement regarding their use, as evidenced by the spirited exchanges between scientists over the relative merits of FFQs vs. 24HRs in surveillance of dietary intake (7–15). For example, Liu (14) concluded that FFQs "may not be appropriate for comparisons of mean intakes among different populations and for estimation of nutrient intake distributions." Our paper sheds further light on this issue, and evaluates, in depth, the use of 24HRs.

In previous work on estimating the distribution of dietary intakes, investigators either presented the distribution of the reported values (16) or, in some studies where repeat 24HRs were used, adjusted the variance of the distribution to exclude within-person variation (17–19). Both approaches implicitly assume that the instrument is unbiased at the individual level,

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[3] Abbreviations used: DLW, doubly labeled water; ISU, Iowa State University; NCI, National Cancer Institute; NRC, National Research Council; OPEN, Observed Protein and Energy Nutrition; UN, urinary nitrogen; 24HR, 24-h recall.

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i.e., that the mean of a sufficient number of repeat observations on an individual will yield a person's true usual intake value. The first approach also assumes that within-person variation is either negligibly small or can be ignored for other reasons. The second approach assumes that, in repeat administrations of the instrument, within-person random errors are independent of each other and of true intake levels, and these assumptions form the basis of the variance adjustment. We regard these conditions, unbiasedness and independence of within-person errors, as the requirements for a valid reference instrument for surveillance.

Recent evidence strongly suggests that common self-report instruments are unlikely to satisfy these requirements. Studies with the few biomarkers of dietary intake that do represent valid reference measurements ("reference" biomarkers), such as doubly labeled water (DLW) for energy and urinary nitrogen (UN) for protein, demonstrate serious biases in dietary self-report instruments (20–29). Such biases are likely to affect the usual intake distributions derived from these instruments.

In this paper, we use data from the Observing Protein and Energy Nutrition (OPEN) Study (28) to examine the performance of an FFQ and of various methods applied to 24HRs for estimating usual intake distributions of energy, protein, and protein density (30) by comparing their results with those derived from reference biomarkers for these nutrients. We also compare reported intakes of potassium with the urinary potassium biomarker.

Finally, we suggest and evaluate methods for adjusting the reported values from 24HRs when reference biomarker measurements for other nutrients are available, in particular, adjusting 24HR reported total energy intake by using the ratio of biomarker protein intake to 24HR reported protein intake.

MATERIALS AND METHODS

Study design. The OPEN Study was conducted by the National Cancer Institute from September 1999 to March 2000. All 484 participants (261 men, 223 women; ages 40–69 y) were healthy volunteer residents of Montgomery County, Maryland (suburban Washington, DC). A complete description of the study can be found elsewhere (28). Each participant was asked to complete an FFQ and a 24HR on 2 occasions. The FFQ was self-administered by each participant within the 2 wk before Visit 1 and ~3 mo later, within the 2 wk prior to Visit 3. The 24HR, administered by an interviewer, was completed at Visit 1 and ~3 mo later at Visit 3. The adopted FFQ was the Diet History Questionnaire developed at NCI (2–6). The 24HR was a highly standardized version that used the 5-pass method developed by the USDA for national dietary surveillance (1).

Participants received their dose of DLW at Visit 1 and returned 2 wk later (Visit 2) to complete the DLW assessment. Repeat DLW measurements were collected in 25 volunteers (14 men, 11 women) who received their second DLW dose at the end of Visit 2 and returned ~2 wk later to complete the assessment. It was assumed that total energy expenditure, which is assessed by DLW, equals energy intake under conditions of stable body weight.

Participants provided two 24-h urine collections during the 2-wk period between Visit 1 and Visit 2, verified for completeness by the 3 para-amino benzoic acid check method (31). Since ~81% of nitrogen intake is excreted through the urine (27,31) and nitrogen constitutes 16% of protein, the UN values were divided by 0.81 and multiplied by 6.25 to estimate individual protein intake. On the basis of several published studies comparing potassium intake with urinary excretion (see Discussion), the values for urinary potassium were divided by 80% to estimate the individual potassium intake. The study was approved by the NCI Special Studies Institutional Review Board for Human Subjects Research.

Estimation of the distribution of usual nutrient intake. The simplest approach to estimating the usual nutrient intake distribution is to use the reported intakes as if they represent true usual intake. When using an FFQ, the usual intake distribution is estimated by the histogram of the reported values. Using a 24HR, when there is only 1 administration of the instrument, investigators often use the mean of the sample to estimate the population mean usual intake and to track changes over time (16,32,33). When there are 2 or more administrations of a 24HR available, some investigators report the mean of the first assessment as the population mean but calculate the SDs and percentiles of the distribution from the mean reported intakes of each individual (16). We investigated the performance of this approach and referred to it as "traditional." We note that the approach is somewhat inconsistent because it adjusts the mean but not the percentiles for the often-observed tendency for repeat 24HR reports to yield lower intakes than the first report. The method does not remove within-person variation in the 24HR.

We also investigated the performance of 2 methods of estimating the distribution of usual intake that do adjust for within-person variation. The first, which we refer to as the National Research Council (NRC) method, was broadly outlined in 1986 (17).[4] The other, known as the Iowa State University (ISU) method, is described in Nusser et al. (18). The 2 methods are conceptually similar but differ in details. Both methods require that a sizable random subgroup of the survey participants complete repeated assessments and are based on the assumption that the dietary instrument is unbiased for usual intake but contains random measurement error (34–37). Both methods assume that the reported nutrient intake is normally distributed in the population, after a suitable transformation. The main difference between the 2 methods is in the scale on which the reported intake is assumed unbiased, and the type of transformation used. The NRC method assumes that reported intake is unbiased on the transformed scale, whereas the ISU method assumes it is unbiased on the original untransformed scale. The NRC method uses, if necessary, a logarithmic, square root, or other power transformation as appears suitable for the data, while the ISU method uses a more complex, nonparametric method of transformation and is more suitable for nutrients with highly skewed distributions (18). Both methods assume that in a series of repeated administrations of the adopted instrument, the true intake is measured with the following: a) zero bias at the first administration and a bias thereafter that depends only on the timing of the administration but not on the individual, and b) random error that is independent of the true intake and independent of the error in the other repeats. The allowance of bias after the first administration is designed to accommodate for the often-observed decrease in mean dietary report at repeat administrations.

Based on these assumptions, both methods, after applying the transformation, i) calculate an adjusted intake for each individual that is "shrunk" toward the sample mean; ii) transform the shrunken value back to the original scale; and iii) then use the resulting values for plotting the histogram of the adjusted distribution or for calculating means, SDs, and percentiles.

The currently recommended approach for estimating usual intake distributions is to apply the NRC method or the more complex ISU method to 24HR measurements (17,38). As mentioned above, however, studies with reference biomarkers have demonstrated serious biases in 24HRs as well as in FFQs (20–29). Thus, it is unlikely that 24HR measurements satisfy the assumptions a and b, listed above, casting into question both current practice and recommendations for estimating usual intake distributions.

To examine these issues, we compared several methods for estimating the usual intake distributions of energy, protein, and protein density for which we had reference biomarker measurements. Because both DLW and adjusted UN are proper reference instruments for energy and protein intake, respectively, on the logarithmic scale, application of the NRC method to these biomarkers should produce unbiased estimates of the distributions of usual intake, and we considered these estimates to be our gold standard. We also studied

[4] Our implementation of the NRC method is included as a supplement to the online posting of this article at www.nutrition.org.

potassium intake [and potassium density (g/MJ)], for which urinary potassium excretion may be a valid reference biomarker. The methods we compared were as follows:

1. Traditional method applied to the first FFQ administration in the OPEN study.
2. Traditional method applied to two 24HRs.
3. NRC method applied to two 24HRs.
4. ISU method applied to two 24HRs.
5. NRC method applied to the reference biomarker (the gold standard).

For each method, we estimated the mean, SEM, SD, and the major percentiles of the usual intake distribution and the percentage of the population consuming less than the 5th or 10th percentile of the gold standard distribution or more than its 90th or 95th percentile. Distributions for men and women were estimated separately.

Adjustment of reported intake. As detailed in the Results section, for both the FFQ and 24HR, we found evidence of reporting bias in energy and protein intake but little bias for protein density. This suggested to us a simple adjustment of reported values of 1 nutrient when using the reported values and the biomarker of the other nutrient. For example, multiplying reported energy intake by the ratio of biomarker protein intake to reported protein intake should give an improved estimate of usual energy intake. Formally, we calculated for each individual as follows: adjusted energy = reported energy × (biomarker protein/reported protein). We then applied the NRC method[4] to these adjusted energy values.

By using the same idea, we also adjusted protein by using energy misreporting; that is, by multiplying by the ratio of biomarker energy to reported energy (if we had a biomarker value of energy intake). We also adjusted potassium by using either energy or protein misreporting. Note, however, that all such adjustments perform well only if the relative error in reporting the 2 nutrients is approximately equal. Thus, we added to the 5 comparative methods described above:

6. NRC method applied to two 24HRs adjusted for protein misreporting.
7. NRC method applied to two 24HRs adjusted for energy misreporting.

It is understood that method 6 cannot be used for estimating the usual protein intake distribution, nor can method 7 be used for estimating the energy intake distribution. Note also that to apply method 6 requires that each survey participant provide 24-h urinary samples that are assessed for nitrogen. To apply method 7 requires that each participant is assessed for energy intake by using DLW, which currently would be prohibitively expensive.

Statistical analysis. When dealing with nutrient intakes adjusted for energy intake, we used nutrient densities (30) (rather than energy-adjusted residuals) calculated for protein as the percentage of total energy coming from protein and for potassium as intake divided by total energy intake (mg/MJ). Protein and potassium densities were calculated for each instrument by using the corresponding nutrient and energy intakes as measured by this instrument.[5]

For all dietary variables, we excluded extreme outlying values that fell outside the interval given by 25th percentile minus twice the interquartile range to 75th percentile plus twice the interquartile range on the logarithmic scale. The logarithmic transformation produced a reasonable approximation to normality for all the nutrients analyzed here and was used both to exclude outliers and with the NRC method. For each variable and each instrument, no more than 6 outlying values for men and 4 for women were excluded from the analyses.

All analyses were performed by using in-house programs written in SAS (version 8.2, 2001; SAS Institute).

RESULTS

Estimation of usual intake distribution for protein and energy via FFQ and 24HR. For all the methods described in the Methods section, we estimated the means (and their SEM) and SD of usual intake of protein and energy in the population (energy and protein entries in **Table 1**). In particular, we compared each method with the gold standard based on the reference biomarker.

The FFQ significantly underestimated the mean usual intake for energy and for protein. Considering energy for men, the reported mean energy intake of 8806 kJ/d was 27% less than the mean of 12,038 kJ/d derived from the biomarker measurements. A similar level of underreporting of energy intake was found among women and also for protein intake in both men and women.

Underreporting was less severe with the 24HR. By using the traditional method (i.e., the first report), the mean reported energy intake was 8% and 12% lower than for the energy biomarker in men and women, respectively. The corresponding figures were 8% and 4% for protein intake. The different methods (traditional, NRC, and ISU) applied to the 24HR reports did not affect the mean values very much (e.g., for energy intake in males, the range for the mean across the 3 methods was 10,775–11,073, a 3% difference).

Regarding the variance, the FFQ grossly overestimated the SD for protein and energy. Using the mean of two 24HR reports also overestimated the SD, but application of the NRC or ISU method improved matters considerably.

We next estimated and compared the percentiles of the distributions on their original scale by using the different methods (energy and protein entries of **Tables 2** and **3**). There was gross disagreement between FFQ-based percentiles and biomarker-based percentiles for both protein and energy. All of the 24HR-based methods severely underestimated the energy percentiles, especially in the lower tail of the distribution. They also underestimated the percentiles in the lower tail of the protein distribution, although, with the ISU method, the underestimation was less severe. Graphical display of the distributions of usual energy intake estimated by different methods for men and women, respectively, confirmed this conclusion.[6]

Estimation of the usual intake distribution for protein density via FFQ and 24HR. We also estimated the mean and SD of protein density by using the different methods (protein density entry of Table 1). Comparison with the biomarker-based distributions suggested that the FFQ and 24HR were much better at estimating protein density than they were at estimating absolute protein or energy; the means were much closer to those found by the biomarker, with a slight tendency to overestimation. The FFQ tended to overestimate variability, whereas the 24HR-based NRC and ISU methods tended to underestimate it.

As before, we found that these results played out in the estimation of the percentiles of the distribution (protein density entry of Tables 2 and 3). The protein density percentiles were estimated reasonably well either by the FFQ or by the 24HR-based NRC or ISU methods, although the 24HR methods tended to overestimate the lower percentiles, whereas the FFQ tended to overestimate the upper percentiles.

Biomarker adjustments to the 24HR. The estimated mean and SD obtained from the biomarker-adjusted 24HR agreed reasonably well with the biomarker-based values for energy and protein absolute intakes (energy and protein entries sections of Table 1). In particular, results were much improved after adjusting the 24HR absolute energy intake by the protein biomarker. The bias was almost entirely eliminated, and the SDs were close to those of the biomarker-based distribution. When we adjusted absolute protein intake by the

[5] The convention we used for dealing with biomarker-based densities is included as a supplement to the online posting of this article at www.nutrition.org.

[6] Graphical displays (Figs. 1–2) are available as a supplement to the online posting of this article at www. nutrition.org.

TABLE 1

Means and SD of usual daily intake among men and women participating in the OPEN study, estimated by different methods

		Men			Women		
Nutrient	Instrument/method	*n*	Mean ± SEM	SD	*n*	Mean ± SEM	SD
Energy, *kJ/d*	Biomarker, NRC[1]	243	12,038 ± 134	1987	206	9657 ± 105	1542
	FFQ, traditional[2]	257	8806 ± 218	3510	222	6831 ± 184	2717
	24HR, traditional[3]	261	11,073 ± 214	2866	223	8516 ± 193	2202
	24HR, NRC[4]	261	10,775 ± 218	2294	223	8179 ± 193	1521
	24HR, ISU[5]	261	11,070 ± 209	2330	223	8520 ± 193	1588
	PA 24HR, NRC[6]	228	12,184 ± 234	1862	193	9249 ± 234	1588
Protein, *g/d*	Biomarker, NRC[1]	228	107.3 ± 1.7	22.8	193	79.5 ± 1.5	16.4
	FFQ, traditional[2]	258	80.7 ± 2.2	35.2	222	61.8 ± 1.8	26.7
	24HR, traditional[3]	261	98.8 ± 2.3	33.4	223	76.4 ± 2.0	23.1
	24HR, NRC[4]	261	94.9 ± 2.2	23.4	223	72.1 ± 2.0	14.3
	24HR, ISU[5]	261	99.0 ± 2.3	23.4	223	76.0 ± 2.0	14.8
	EA 24HR, NRC[7]	245	107.1 ± 2.3	25.2	206	84.0 ± 2.1	17.6
Protein density, %	Biomarker, NRC[1]	213	14.9 ± 0.21	2.43	179	13.9 ± 0.23	2.53
	FFQ, traditional[2]	254	15.4 ± 0.18	2.87	221	15.3 ± 0.22	3.22
	24HR, traditional[3]	261	15.2 ± 0.27	3.56	223	15.1 ± 0.28	3.35
	24HR, NRC[4]	261	14.8 ± 0.25	2.24	223	14.6 ± 0.27	1.92
	24HR, ISU[5]	261	15.2 ± 0.26	2.26	223	15.1 ± 0.28	1.95
Potassium, *mg/d*	Biomarker, NRC[1]	228	3548 ± 70	909	193	2769 ± 70	750
	FFQ, traditional[2]	258	3570 ± 90	1446	222	2976 ± 73	1087
	24HR, traditional[3]	261	3606 ± 80	1109	223	2919 ± 75	908
	24HR, NRC[4]	261	3472 ± 76	833	223	2783 ± 71	673
	24HR, ISU[5]	261	3611 ± 81	852	223	2923 ± 75	728
	EA 24HR, NRC[7]	245	3887 ± 79	850	206	3308 ± 82	875
	PA 24HR, NRC[6]	228	3962 ± 96	788	193	3131 ± 97	852
Potassium density, *mg/MJ*	Biomarker, NRC[1]	213	297 ± 6.0	75.1	179	293 ± 6.7	72.5
	FFQ, traditional[2]	259	413 ± 6.4	104.0	222	455 ± 7.9	118.1
	24HR, traditional[3]	261	335 ± 5.7	78.8	223	357 ± 8.4	102.5
	24HR, NRC[4]	261	326 ± 5.7	55.9	223	346 ± 8.1	81.1
	24HR, ISU[5]	261	336 ± 6.0	57.3	223	357 ± 8.1	87.2

[1] NRC method (17) applied to biomarker values (regarded as the gold standard).
[2] Mean and SD are calculated from the first FFQ values.
[3] Mean is calculated from the first 24HR values, SD is calculated from the means of the two 24HR values.
[4] NRC method (17) applied to 24HR values.
[5] ISU method (18) applied to 24HR values.
[6] NRC method (17) applied to the protein biomarker-adjusted 24HR value.
[7] NRC method (17) applied to the energy biomarker-adjusted 24HR value.

energy biomarker, agreement with the protein biomarker-based results also appeared quite good (energy and protein entries of Tables 1–3).[6]

Percentages of individuals exceeding or failing to exceed certain cutoffs. For each method, we also compared the percentages of individuals falling below or above the 5th, 10th, 90th, and 95th percentiles of the biomarker distribution (**Table 4**). For a method that works well, values close to 5, 10, 10, and 5, respectively, would be expected. The results mirrored those of Tables 1–3. There were gross discrepancies in many cases, and the only methods that yielded reasonable agreement with biomarker-based results were as follows: for energy, the protein biomarker-adjusted 24HR; for protein, the energy biomarker-adjusted 24HR, with the ISU 24HR-based method as a possible second best; and for protein density, the FFQ or any 24HR-based method.

Results for potassium intake. In contrast to earlier results, there appeared to be no systematic underreporting of absolute potassium intake when using the FFQ nor when using the 24HR (potassium entry of **Table 1**). However, the FFQ overestimated the SD of the distribution, whereas the 24HR-based methods, especially the NRC and ISU methods, performed quite well. Similarly, the results on the percentiles of the distribution for potassium indicated that the NRC or the ISU 24HR methods worked well for this nutrient (potassium entry of Tables 2–4).

Comparison with the mean of the biomarker-based distribution of potassium density showed that both FFQ and 24HR overestimated the mean, with the FFQ performing worse (potassium density entry of Table 1). This overestimation was expected because absolute potassium intake was well estimated by the self-report instruments, whereas energy intake was underreported when using these instruments. Accordingly, none of the methods came close in estimating the potassium density percentiles (potassium density entry of Tables 2–4). The agreement improved by using an adjusted potassium density equal to the ISU 24HR potassium intake divided by the protein-corrected 24HR energy, although we do not present the results here.

DISCUSSION

We were able to compare the distributions of usual intake estimated from self-administered FFQ or interviewer-administered 24HR with the distributions derived from biomarkers. The estimated distributions that we presented are intended as a methodological comparison and should not be interpreted as usual intake distributions of a U.S. population, given that the

TABLE 2

Percentiles of usual daily intake among men participating in the OPEN study, estimated by different methods

Nutrient	Instrument/method	Percentiles						
		5	10	25	50	75	90	95
Energy, *kJ/d*	Biomarker, NRC[1]	9208	9823	10,739	11,782	13,072	14,499	15,558
	FFQ, traditional[2]	4084	4931	6501	8143	10,664	14,210	15,856
	24HR, traditional[3]	6563	7339	8998	10,665	12,458	14,465	15,841
	24HR, NRC[4]	7291	7898	9248	10,595	11,988	13,627	14,718
	24HR, ISU[5]	7360	8261	9416	10,861	12,496	14,147	15,223
	PA 24HR, NRC[6]	9530	9964	10,821	11,970	13,318	14,692	15,713
Protein, *g/d*	Biomarker, NRC[1]	74.8	80.8	91.4	105.2	120.5	136.7	143.7
	FFQ, traditional[2]	35.2	41.8	58.8	74.3	98.0	126.7	148.2
	24HR, traditional[3]	51.4	61.4	77.2	98.5	119.6	138.0	164.8
	24HR, NRC[4]	59.0	66.9	78.3	92.8	109.0	121.6	132.3
	24HR, ISU[5]	65.4	71.3	82.4	96.5	113.0	130.0	141.3
	EA 24HR, NRC[7]	69.3	78.1	89.3	105.0	120.5	140.1	151.2
Protein density, %	Biomarker, NRC[1]	10.9	11.6	13.3	14.7	16.5	18.0	19.2
	FFQ, traditional[2]	10.6	11.7	13.6	15.4	17.1	19.0	20.7
	24HR, traditional[3]	10.0	11.5	13.1	15.3	17.8	21.0	22.0
	24HR, NRC[4]	11.1	12.2	13.2	14.7	16.3	18.0	18.5
	24HR, ISU[5]	11.8	12.4	13.6	15.0	16.6	18.1	19.1
Potassium, *mg/d*	Biomarker, NRC[1]	2173	2403	2893	3486	4129	4698	5104
	FFQ, traditional[2]	1860	2028	2551	3231	4315	5569	6570
	24HR, traditional[3]	1921	2178	2840	3493	4310	5109	5503
	24HR, NRC[4]	2171	2384	2920	3392	4014	4610	4914
	24HR, ISU[5]	2348	2580	3005	3537	4136	4737	5127
	EA 24HR, NRC[7]	2623	2917	3330	3802	4376	4887	5298
	PA 24HR, NRC[6]	2805	3068	3376	3910	4361	5029	5352
Potassium density, *mg/MJ*	Biomarker, NRC[1]	185	205	241	298	340	388	440
	FFQ, traditional[2]	247	282	347	405	470	538	595
	24HR, traditional[3]	220	242	280	334	387	449	485
	24HR, NRC[4]	239	255	287	324	362	401	422
	24HR, ISU[5]	247	265	295	332	372	411	435

[1] NRC method (17) applied to biomarker values (regarded as the gold standard).
[2] Percentiles of the first FFQ values.
[3] Percentiles of the means of the two 24HR values.
[4] NRC method (17) applied to 24HR values.
[5] ISU method (18) applied to 24HR values.
[6] NRC method (17) applied to the protein biomarker-adjusted 24HR value.
[7] NRC method (17) applied to the energy biomarker-adjusted 24HR value.

OPEN study population comprises volunteers who were not randomly selected.

For absolute protein and energy intakes, we found that the FFQ severely underestimated the mean and severely overestimated the SD. It therefore appears of little use in estimating usual intake distributions of absolute nutrients. This finding reinforced our previous conclusion [made in relation to the attenuation of relative risks in epidemiologic studies (27,29)] about the inadvisability of using an FFQ in studies of absolute intakes. The FFQ appeared to be better at measuring protein density than absolute protein, as previously claimed (30). Further, it is likely that other widely used FFQs would perform similarly, given results of comparisons of this instrument to the Block and Willett FFQs (5).

Our results indicated that using the first 24HR for estimating mean absolute intakes was more successful than using an FFQ but that some underestimation is still evident for energy (8–12%) and protein intake (4–8%). [These levels of underreporting are slightly lower than previous reports from the OPEN Study (28), which used the mean of two 24HRs rather than the first 24HR.] The 24HR instrument appeared to do better at estimating the SD, after the NRC or ISU method was applied; however, because of the underestimation problem, these methods did not reliably estimate percentiles of the distribution of usual intake of energy and also were not very satisfactory for protein. For example, the 10th percentiles of the distribution of actual energy intake for men and women were estimated as the 32nd and 35th percentiles, respectively, by the 24HR-based ISU method. These problems may have major public health implications, especially in the context of understanding what percentage of the population meets dietary recommended intakes. The question is: can anything better be achieved?

We suggested in this paper an adjustment method that may prove useful, especially for energy intake. Our adjustment to 24HR reported energy intake, based on assessments of UN *on each individual*, markedly improved the accuracy of the 24HR for estimating usual energy intake distributions. In the example of the previous paragraph, the 10th percentile of the distribution of absolute energy intake would now be estimated as the 8th percentile for men and the 17th percentile for women, using this protein-adjusted 24HR energy. The option of adjusting energy intake by using UN measurements thus deserves serious consideration, especially in view of the importance of energy intake to the current problems of obesity in the United States.

Before the adoption of such an approach, several questions need to be considered carefully. Is it necessary to take two 24-h

TABLE 3

Percentiles of usual daily intake among women participating in the OPEN study, estimated by different methods

		Percentiles						
Nutrient	Instrument/method	5	10	25	50	75	90	95
Energy, *kJ/d*	Biomarker, NRC[1]	7444	7836	8596	9583	10,512	11,616	12,658
	FFQ, traditional[2]	3337	4072	4911	6346	8338	9998	11,647
	24HR, traditional[3]	4935	5616	6704	8156	9755	11,124	11,897
	24HR, NRC[4]	5747	6203	7124	8083	9148	10,141	10,693
	24HR, ISU[5]	6089	6561	7403	8421	9529	10,607	11,291
	PA 24HR, NRC[6]	6984	7273	8232	9131	10,105	11,115	11,598
Protein, *g/d*	Biomarker, NRC[1]	57.0	62.8	69.2	75.0	88.4	98.3	108.4
	FFQ, traditional[2]	27.0	33.3	43.9	56.4	76.4	92.0	108.2
	24HR, traditional[3]	41.3	48.6	57.2	71.2	87.6	105.4	119.1
	24HR, NRC[4]	50.7	54.9	61.4	71.2	80.7	91.1	99.4
	24HR, ISU[5]	53.7	57.9	65.5	74.9	85.3	95.5	102.1
	EA 24HR, NRC[7]	58.6	62.7	71.9	82.7	93.9	106.5	116.6
Protein density, %	Biomarker, NRC[1]	9.8	10.7	12.4	13.8	15.2	17.0	18.5
	FFQ, traditional[2]	10.2	11.4	13.1	15.1	17.2	19.4	20.9
	24HR, traditional[3]	10.0	11.1	13.2	14.9	17.3	20.0	21.1
	24HR, NRC[4]	11.3	12.3	13.5	14.5	15.8	17.3	17.7
	24HR, ISU[5]	12.1	12.7	13.8	15.0	16.4	17.7	18.5
Potassium, *mg/d*	Biomarker, NRC[1]	1766	1924	2253	2658	3177	3685	3934
	FFQ, traditional[2]	1549	1755	2169	2833	3601	4274	4749
	24HR, traditional[3]	1612	1784	2239	2814	3395	4058	4388
	24HR, NRC[4]	1820	1951	2290	2770	3165	3682	3910
	24HR, ISU[5]	1843	2041	2405	2860	3372	3886	4219
	EA 24HR, NRC[7]	2144	2296	2655	3237	3738	4466	5005
	PA 24HR, NRC[6]	1967	2265	2583	3032	3632	4056	4513
Potassium density, *mg/MJ*	Biomarker, NRC[1]	178	210	242	287	331	391	437
	FFQ, traditional[2]	279	314	378	442	519	607	682
	24HR, traditional[3]	214	248	283	355	424	498	547
	24HR, NRC[4]	226	256	284	343	395	453	493
	24HR, ISU[5]	229	252	295	349	410	472	513

[1] NRC method (17) applied to biomarker values (regarded as the gold standard).
[2] Percentiles of the first FFQ values.
[3] Percentiles of the means of the two 24HR values.
[4] NRC method (17) applied to 24HR values.
[5] ISU method (18) applied to 24HR values.
[6] NRC method (17) applied to the protein biomarker-adjusted 24HR value.
[7] NRC method (17) applied to the energy biomarker-adjusted 24HR value.

urinary samples from all participants? Could the method of estimating the usual energy intake distribution be implemented if by design some participants were to submit only 1 sample, and others none? What compliance problems would be encountered, and what proportion of participants would submit satisfactory urine samples? What would be the cost of adding the extra UN assessments in terms of time, money, field staff, laboratory equipment, and personnel? Would these costs be justified by the increased quality of the information obtained? We do not attempt to answer these questions in this paper, but we argue that the results that we presented for estimating usual energy intake are good enough to require their serious consideration. We therefore advocate further research into these questions.

In contrast to the results for energy and protein intake, there appeared to be no systematic underreporting of absolute potassium intake when using the FFQ, nor when using the 24HR. There are 2 possible explanations for this. It may be that there is much less underreporting of potassium-containing foods compared with other energy-providing foods, or it may be that our urinary potassium biomarker did not capture the full intake of potassium. We will consider each of these possibilities in turn.

The possibility that some foods are underreported more than others has been proposed before (39–41) and seems intuitively reasonable, given that underreporting is a sociological/psychological phenomenon (22). Moreover, our finding that, among women, underreporting of energy (12%) appears to be about triple the level of underreporting of protein (4%) supports this possibility. Among the major sources of potassium in the U.S. diet, only beef and milk—accounting for <17%—are also major sources of protein and energy (42). Thus, there is not much overlap in the food sources of these constituents, and differential underreporting is entirely possible. Although urinary potassium excretion has not been studied as extensively as UN, there are, nevertheless, several published studies comparing potassium intake with urinary excretion (43–49). In a well-designed study, Mickelson et al. (43) report a stable proportion of (of ~0.83) potassium intake excreted intourine in 20 normal males, although this proportion has shown considerable between-person variation (0.61–1.00) and between-study variation (0.72–0.87) in other reports. It is still not entirely clear whether this variation is due to methodological problems in measuring true potassium intake and collecting complete urinary output or because the proportion really does depend on individual characteristics or environmental conditions. Thus, although the evidence for the potassium marker points in a generally positive direction,

TABLE 4

Percentage of men and women participating in the OPEN study having usual intake less than or greater than specified biomarker-based percentiles, estimated by different methods

		Men				Women			
Nutrient	Instrument/method	<5th[1]	<10th[2]	>90th[3]	>95th[4]	<5th[1]	<10th[2]	>90th[3]	>95th[4]
Energy, *kJ/d*	Biomarker, NRC[5]	5	10	10	5	5	10	10	5
	FFQ, traditional[6]	62	68	9	6	66	71	5	4
	24HR, traditional[7]	28	37	9	6	38	45	7	3
	24HR, NRC[8]	24	35	6	3	33	42	2	0.4
	24HR, ISU[9]	22	32	8	4	26	35	3	1
	PA 24HR, NRC[10]	3	8	11	6	12	17	5	2
Protein, *g/d*	Biomarker, NRC[5]	5	10	10	5	5	10	10	5
	FFQ, traditional[6]	51	57	7	6	51	58	9	5
	24HR, traditional[7]	23	32	11	9	24	34	15	8
	24HR, NRC[8]	19	31	5	4	13	29	6	1
	24HR, ISU[9]	14	22	7	4	9	19	8	2
	EA 24HR, NRC[11]	7	14	12	8	5	10	21	9
Protein density, %	Biomarker, NRC[5]	5	10	10	5	5	10	10	5
	FFQ, traditional[6]	6	9	14	8	4	7	28	17
	24HR, traditional[7]	8	10	23	16	4	8	28	17
	24HR, NRC[8]	4	8	9	3	0	3	12	3
	24HR, ISU[9]	1	4	11	5	0.1	1	16	5
Potassium, *mg/d*	Biomarker, NRC[5]	5	10	10	5	5	10	10	5
	FFQ, traditional[6]	14	22	17	13	11	15	23	20
	24HR, traditional[7]	10	14	15	10	10	13	18	13
	24HR, NRC[8]	5	11	8	2	4	9	10	5
	24HR, ISU[9]	3	6	11	5	4	7	15	9
	EA 24HR, NRC[11]	1	4	14	8	1	2	29	20
	PA 24HR, NRC[10]	0	0	16	9	3	4	24	15
Potassium density, *mg/MJ*	Biomarker, NRC[5]	5	10	10	5	5	10	10	5
	FFQ, traditional[6]	0	0	59	37	0	0.5	72	51
	24HR, traditional[7]	0.4	2	24	12	1	4	35	22
	24HR, NRC[8]	0	0.4	14	4	0.4	3	26	14
	24HR, ISU[9]	0.1	0.5	18	4	1	2	32	17

[1] Percentage with usual intake less than the 5th percentile of the biomarker-based distribution.
[2] Percentage with usual intake less than the 10th percentile of the biomarker-based distribution.
[3] Percentage with usual intake more than the 90th percentile of the biomarker-based distribution.
[4] Percentage with usual intake more than the 95th percentile of the biomarker-based distribution.
[5] NRC (17) method applied to biomarker values (regarded as the gold standard).
[6] Based on percentiles of the first FFQ values.
[7] Based on percentiles of the means of the two 24HR values.
[8] NRC method (17) applied to 24HR values.
[9] ISU method (18) applied to 24HR values.
[10] NRC method (17) applied to the protein biomarker-adjusted 24HR value.
[11] NRC method (17) applied to the energy biomarker-adjusted 24HR value.

there is still some doubt as to whether the proportion correction applied in our study (0.80) is in fact valid. If it was too large, then true potassium intake would be underestimated by the biomarker, which could create the false impression that potassium intake was not underreported on the FFQ or 24HR.

In summary, the potassium results may be interpreted in 1 of 2 ways. The simpler interpretation is to defer drawing conclusions from them until firmer evidence regarding the potassium biomarker is obtained. In that case, it seems possible that our results for energy might extend to other nutrients that are sufficiently correlated with protein intake and that a protein-biomarker adjustment of 24HR reported intakes of other nutrients might yield improved estimates of the percentiles of usual intake distributions for which there are currently no reliable biomarkers.

The more complex interpretation is to accept the potassium results and infer that there are substantial differences in the misreporting of different foods and, therefore, also nutrients. If this were the case, we would have to admit at least temporary ignorance of which nutrients would be estimated well by 24HRs and which would not. Our present knowledge would simply extend to placing protein and energy in the "bad" list and potassium in the "good" list. A strong interest in energy intake would still suggest including a protein biomarker as part of the survey.

It therefore is clear that we need to know more about the potassium biomarker before advocating the use of a protein-marker adjustment for estimating nutrient intakes other than energy. Larger controlled feeding studies linking potassium intake to potassium excretion are needed to establish more clearly the extent of individual variation in the intake/excretion ratio and its dependence, if any, on the level of potassium intake and other factors.

Finally, our data allowed cross-sectional estimates of the distribution of usual intakes but not distributions of longitudinal change. It is entirely possible that 24HR or FFQ will do a reasonable job of tracking relative changes in mean intake over time, even though poorly estimating the actual mean.

Longitudinal biomarker studies will be necessary to check whether self-report instruments are adequate for this task.

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